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# Analysis of the Fish Community on Tidal-Freshwater Constructed Reefs

Briana Langford
*Virginia Commonwealth University*

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science at Virginia Commonwealth University.

by
Briana C. Langford
B.S. University of North Carolina, Asheville, 2008

Thesis Director: Dr. Stephen McIninch, Environmental Science

Virginia Commonwealth University
Richmond, VA
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Abstract

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Constructed reefs are used successfully in marine systems to enhance spawning habitat; this study examines the effectiveness of constructed reefs in a tidal-freshwater river. Fish abundance, species diversity and richness, residency, water column position, reproductive guilds, and feeding guilds were analyzed on two constructed reefs in the tidal-freshwater James River and compared to silted regions representing the primary substrate in the river. Reefs were sampled using hydroacoustics, electroshocking, gillnetting, trawling, and egg mats. The constructed reefs had a greater proportion of fish that broadcast spawn over hard substrate and a trend of more overall individual, residential, and demersal fish. The results suggest that the reefs may be attracting a different fish community than their respective comparison sites, though additional research on the effectiveness of constructed reefs in tidal-freshwater rivers is recommended.

# I. Introduction

Anthropogenic influences have increased the sedimentation of the James River; potentially threatening aquatic taxa that rely on clean, rocky substrates for spawning. The eggs of multiple fish species are adhesive in order to stick to hard substrates; unfortunately, this adhesiveness also attracts silt (Ward 1992). Silt cover limits the amount of oxygen that permeates the eggs and hampers the adhesiveness that keeps eggs stationary, negatively impacting the larvae's development (Barton 2007). The addition of clean rock into the system increases the suitable spawning habitat surface area in the James River, potentially increasing local fish populations. Beginning in 2009, Virginia Commonwealth University (VCU) with its partners United States Fish and Wildlife Service (USFWS), the National Oceanic and Atmospheric Administration (NOAA), Fish America Foundation (FAF), the US Army Corps of Engineers, the James River Association (JRA), and two area quarry companies, Luck Stone and Vulcan, created the first constructed reef system for Atlantic sturgeon *Acipenser oxyrinchus oxyrinchus* in North America by constructing spawning habitat in the tidal-freshwater area of the James River.

Atlantic sturgeon have been heavily harvested since the first European colonists arrived in North America. Years of exploitation have decimated the population; peak commercial landings, over 3,000 metric tons in the late 19$^{th}$ century, dropped to approximately 300 metric tons in the early 20$^{th}$ century (Smith and Clungston 2002). In 1998, the Atlantic States Marine Fisheries Commission implemented a moratorium on the fishing of wild Atlantic sturgeon. The population has been slow to recover because of late sexual maturation, habitat degradation, and dams that block migration to their spawning grounds (Grunwald et al. 2008; Smith and Clungston 2002; NMFS 2012). The Chesapeake Bay, New York Bight, Carolina, and South Atlantic populations of Atlantic sturgeon have been recently listed (2012) as endangered under the United States Endangered Species Act. Because spawning habitat limitation is a major impediment to Atlantic sturgeon recovery, emphasis has been placed on restoration of their breeding habitat (NMFS 2012). Artificial reefs constructed to enhance sturgeon spawning habitat also create spawning habitat for other ecologically and commercially important fish, such as white perch *Morone americana*, striped bass *M. saxatilis*, and several different types of shad (Auld and Schubel 1978; Jenkins and Burkhead 1994). Many fish species utilize rocky areas for protection from predators, nursery habitat, and/or foraging habitat (Barton 2007).

Although new to the James River, constructed reefs have been used as fish attraction devices for centuries (Seaman and Sprague 1991). Early reefs were designed to attract fish for harvesting, which sometimes led to population declines because of overexploitation (Bohnsack et al. 1997; Lindbergh 1997). Similarly, two artificial reefs off the coast of South Carolina constructed in 1963 and 1973 to attract fish for anglers led to an overall population decline because of high catches (Buchanan et al. 1974). More recently, these structures have become a tool to aid in the rehabilitation of species whose populations were damaged because of loss of habitat or breeding grounds (Jones 1982; Santos et al. 2008). For example, Layheye et al. (1992) expanded lake sturgeon *Acipenser fulvescens* spawning habitat by expanding Des Prairies (Quebec) power plant's spillway, leading to the increase of egg abundance and egg to larvae survival rate for lake sturgeon. Most created spawning structures are in marine waters (i.e. on bases of petroleum platforms in temperate regions or near coral reefs in tropical areas) or in freshwater lakes. Tidal-freshwater species composition and physical conditions are different than in marine and freshwater reefs systems, which could result in a difference in constructed reef use by fishes (Table 1; Sepkoski and Rex 1974; Moyle and Cech 2004; Van Damme et al. 2009). Presently, there is little information about constructed reefs deployed in rivers that are tidally influenced.

The tidal-freshwater James River combines physical, chemical, and biological characteristics from the freshwater upstream area with those found in the brackish estuary at its mouth. There are two daily tidal shifts and a salinity that is <0.05‰, though higher values are found during dry summer months. The ecosystem is dynamic, changing seasonally and diurnally, leading it to be a relatively harsh environment for resident taxa. Fish community composition is influenced by species in adjacent tributaries and upstream freshwater regions, migrating species from neighboring estuaries/oceans, and introduced species, resulting in a region that has a more diverse taxa than the adjacent freshwater and estuarine areas (Viverette et al. 2007). Native anadromous fish (i.e. blueback herring *Alosa aestivalis,* striped bass, Atlantic sturgeon) that travel through the tidal James River are an important energy and nutrient source for the area (Garman and Macko 1998; Welcomme et al. 2006); the constructed reefs may attract these key species by creating suitable spawning habitat that is limited in this region, as well as resident and demersal species seeking rocky areas for feeding and protection (Miller, 1960; Mansueti 1964; Lambou 1965; Mullens et al. 1986). Constructed reefs may function differently in this transitional environment.

This project examined if constructed reefs are effective for restoration in a tidal-freshwater river. We analyzed fish abundance, size, and species diversity and richness for both reef areas and adjacent silted regions. Species were assessed by residency, water column position preference, reproductive substrate, and feeding guilds. This study specifically tests if the two constructed reefs attract a more abundant and/or different fish community than nearby silted areas of a similar depth and size.

## II. Materials and Methods

### A. Site Locations

The reefs were constructed adjacent to channels dredged by the US Army Corps of Engineers that are used as short cuts for container ships through natural river oxbows, but close enough to deep water areas with a strong current to attract passing fish. Locations were chosen based on the abundance of Atlantic sturgeon during the fall, generally uniformly silted substrate of the area, and adjacency to main river channel. Reef 1 was constructed perpendicular to the shore of Presquile Island, near the channel at river mile 128. It was completed in February 2010 with a donation of rock from Luck Stone (Figure 1). Reef 2 is further upstream than the first structure, near the dredged channel by Jones Neck Island at river mile 144, and was built in March 2011 with donated material from Vulcan (Figure 1). The two sites have similar characteristics, but Reef 2 is at a lower risk of being affected by salinity intrusion that typically occurs in the late summer (Atlantic sturgeon embryos are sensitive to saltwater, and adults may not breed on the reefs if there is any detectable salinity; Van Eenennaam et al. 1996). One silted comparison site was chosen near each reef and was of a similar depth, area, and flow velocity to the reefs they are adjacent to; the comparison site related to Reef 1 was labeled as Comparison 1 and the comparison site related to Reef 2 was labeled as Comparison 2.

### B. Site Descriptions

Both reefs are made of approximately 2,200 metric tons of aggregate native Petersburg formation granite ranging from 10 centimeters to half a meter in diameter and were built in tidally influenced areas with mostly fine substrate. The depth to the top of Reef 1 averages about 4.5 meters at high tide while Reef 2 averages about 5.5 meters. Reef 1 is one large singular mound of cobble and rock. It runs perpendicular to the shoreline and is the more compact of the two reefs, with a surface area of approximately 6,350 $m^2$. The height of the reef is approximately 1 meter above the silted bottom. Reef 2 is comprised of multiple small piles of rock in two main rows within a surface area of approximately 6,450 $m^2$. The rock piles average about 1.5 meters above the silted bottom. This reef is more spread out, longer and narrower, running parallel to the shoreline. Locations, shape, and size of the reefs are indicated in Figure 2 and bottom structure differences between the reefs and their respective comparison sites is shown in Figure 3. Both constructed reefs are close to 15 meter deep sections of the river that are heavily used by many different fish species (personal observation). The intent was to increase the number of attracted individuals by being in close proximity of these areas rich in fish.

### C. Study Design

Reef 1 was sampled monthly from October 2010 to March 2012. Because this reef was constructed in February 2010, seven months prior to the commencement of observations, the data show how an already established reef functions during different seasons. Reef 2 was monitored from April 2011 until March 2012. In order to accurately measure the quantity and diversity of fish on the reef, four collection methods were utilized: hydroacoustics, electroshocking, gillnetting, trawling, and egg mats. Water visibility is minimal in all locations, which prevents visual surveys that are commonly utilized on constructed reefs. Hydroacoustic data were gathered once a month at each site for approximately 10 minutes per sample day. The electroshocking boat immediately followed the acoustic survey when the water temperatures were above 6 degrees Celsius; electroshocking becomes ineffective in low water temperatures (Johnson et al. 2008). Sampling using gillnets was done four times throughout the study and trawling occurred twice. Assumptions made about the collected data were: 1) species captured by electroshocking were the same species being recorded by the acoustic equipment; 2) environmental sampling conditions were the same at the reefs and their comparison sites at the time they were sampled (weather, temperature, turbidity); and 3) the reefs and their comparison sites were independent but equally affected by seasonal changes.

### D. Hydroacoustics

Quantifying the fish community that use tidal-freshwater habitats can be difficult because most conventional data gathering methods identify only a portion of the fish present. Hydroacoustics resolves this by accurately counting most fish within a certain size range beneath the boat (Stanely et al. 1994). A transducer sends sound waves (pings) into the water, and the decibels of the reflected echo indicate the “target strength” (TS); higher TS are equivalent to a larger fish because the amount of sound reflected will be greater (Simmonds and MacLennan, 2005). Hydroacoustics can be used to estimate biomass, swimming direction and speed, depth, size, and abundance of individuals noninvasively (Auer et al. 2007; Fabi and Sala 2002; Boswell et al. 2010). Traditional data gathering methods are exclusive to what fish physically get captured. Gillnetting only samples the size of fish that can get caught in the mesh size being used. Trawling is particular to demersal or mid-pelagic regions of the water column and is difficult to implement on the constructed reefs because of the rocky substrate and small area (Stanely et al. 1994; Stanely and Wilson 2000). Electroshocking can cause some stunned demersal fish to stay on the bottom and can be biased by the difficulty of detecting juvenile fish and small fish species and its ineffectiveness in low water temperatures and salinity (Johnson et al. 2008). Visual surveys are not possible in the James River because of high turbidity that limits visibility. Occasionally these traditional methods remove fish from the reef and may lead to specimen mortalities; hydroacoustic methods do not require direct handling of the fish, with no resulting specimen loss.

A 430 kHz Biosonics DT-X 06-134 Digital Scientific Echosounder with a splitbeam transducer was mounted on the port side of a 25 foot long research vessel. The transducer faced downward, submerged roughly 30 cm under water. The depth of the study site and water temperature was set within the Visual Acquisition™ 6 Program each sample day. Analysis started at 0.5 meters to remove acoustic noise caused by air bubbles formed by movement of the boat that can disrupt data processing. The transducer was periodically calibrated following standard procedures following Foote et al. (1987). The transducer was set to record 5-10 pings per second at a collection threshold of -130 dB. The boat followed the paths indicated in Figure 4. Each path was particular for each reef and a similar path was run for the respective comparison sites. Data was assessed using Visual Analyzer™ 4.2 software for fish individual abundance, size, and location in the water column. Settings for analysis are listed in Table 2, and a sample acoustic return is shown in Figure 5. A tool within Visual Analyzer™ calculates bottom depth based on the strength of acoustic returns. Because this calculation was not always accurate, the bottom was manually marked within the program to ensure no inorganic material on the river floor was mistaken for a fish. Target strength (TS) range was set at -20 dB to -64 dB, which localizes most sizes of fishes found in the James River while reducing the likelihood of identifying large or small inorganic objects as fish. This information was then used to determine the relative size of fishes within both reef structures and comparison sites. The number of individuals detected in each strata (benthic, mid-pelagic, and pelagic) was divided by the total number of individuals caught that day to find per strata ratios. Number of fishes recorded was transformed into catch per unit effort (CPUE), calculated as:

$$\text{CPUE} = \text{\# of fish recorded / minutes recording}$$

Individual fish pinged can be identified to species using the hydroacoustic equipment based on the TS range known for a given species combined with water column position preference and time of year. Species were not identified acoustically in this study because specific TS ranges of the species in the James River pinged by a 430 kHz transducer are unknown. There is literature on TS ranges for several of the James River species, but the data was obtained at lower frequencies, making the TS different from what would be seen with a 430 kHz transducer (Frouzova et al. 2005; Hartman and Nagy 2005). Knowledge of species TS range is the key to the accurate identification of species with hyrdoacoustic equipment (Horne 2000).

E. Electroshocking

Electroshocking was utilized to identify species present. Within 2-3 minutes of an acoustic transect, the pattern was duplicated with an electroshocking vessel (Smith-Root Inc., Vancouver, Washington), first at a frequency of 120 Hz (6 amps) and then at a lower frequency of 7.5 Hz (0.5 amps); some bottom dwelling species (i.e. several species of catfish) do not float to the surface following a high frequency shock but will emerge if a lower frequency is utilized (Johnson et al. 2008). Fish were captured by one or two dip netters at the front of the boat; if the overabundance of one species led to difficulty netting all individuals, then the number of fish was estimated. Electroshocking effort used on the constructed reefs and their respective comparison sites was held as constant as possible. Fish were identified to species, enumerated, examined, and released. Individual numbers were transformed into the CPUE:

$$\text{CPUE} = \text{total \# of individuals} / \text{minutes shocked}$$

F. Gillnetting, Trawling, and Egg Mats

Hydroacoustics and electroshocking are useful methods to determine what fish are on the sites at a given moment, but results can be influenced by time of day, tide, and motor noise (Thorne 1994). Gillnetting was utilized several times over the course of the study in order to capture diurnal shifts in species. Nets were deployed on the sites for 8-24 hours (shorter periods of time during warmer months to decrease the mortality of fish in the nets) using four gillnets: two with five 20 foot panels that ranged from 2 to 6 inch mesh size and two 300 foot long nets with 3 inch mesh. One net was set at each site. A small trawl net was used twice on Reef 1 to detect bottom-dwelling species that may not be captured by gillnets or electroshocking (i.e. hogchoker *Trinectes maculatus* and young Atlantic sturgeon). Since this data was sparse and was not obtained simultaneously with the hydroacoustic and electroshocking studies, it was not included in the data analysis.

Egg mats, constructed with rebar and floor buffer pads, were used to collect eggs laid on the reefs (Marchant and Shutter, 1996). In the spring, thirty mats were placed at each site in four lines with five lines with either five or six mats per line on Reef 1 and six or seven mats per line at the Reef 2, parallel to the nearest shore. In the fall, fifteen mats at each site at Reef 1 and Reef 2 with one line of seven and one line of eight at each site. The egg mats were checked weekly and egg samples were collected for identification. Information gathered was used to determine what species were spawning on the constructed reefs.

### G. Community Analysis

In order to assess the utilization of constructed reef habitats we compared fish data and functional guilds classification between the constructed reefs and their respective comparison sites. Fish were placed into the following categories: resident status (resident or migratory), water column position, reproductive, and feeding guilds. Species were also labeled as either native or introduced to the James River and by commercial importance (none, historical, recreational, secondary commercial, and primary commercial fisheries) for discussion purposes, though these divisions were not tested statistically (Table 3). Diversity and richness were used to indicate if species were equally represented at the constructed reefs and their comparison sites. Diversity refers to the number of species that have an equally proportional abundance of individuals within them; therefore, if a few species are dominant, the diversity would be low (Zar 2010). Species richness was determined by summing the number of species per sample date. Species diversity was tested using the Shannon-Weiner index and was calculated using the statistical program R as follows (R development core team 2012):

$$H' = -\text{sum } (P_i \ln[P_i])$$
$$P_i = \text{\# of observations in a species/sample size}$$

We specifically tested the hypothesis that the constructed reefs have higher fish abundance and greater species diversity because the reefs provide a rare, hard substrate within a homogenously silted area.

Resident species are fish that would reside on or in close proximity to the constructed reefs year round; potadromous species that primarily migrate within freshwater (i.e. gizzard shad *Dorosoma cepedianum* and threadfin shad *D. petenense*) were considered transient for this study because they exhibit a small spawning migration from brackish areas to the tidal-freshwater region where the constructed reefs were built (Jones et al. 1978; Jenkins and Burkhead 1994). Like on marine artificial reefs, resident species may stay on the reefs year round, drawn to the rocky substrate for feeding and protection (Bohnsack et al. 1994; Golani and Diamant 1999). It was hypothesized that resident fish would be more common on the constructed reefs and therefore transient species would be proportionally greater on the comparison sites.

If hard-bottomed habitat is limited in the area, then the structure difference that the constructed reefs provide may draw more demersal species dependent on rocky areas than nearby silted areas. These fish then may remain for a longer period of time than pelagic fish because of the rarity of rocky habitat, therefore increasing abundance of demersal fish on the reefs. Vertical water column position was identified in two ways: one, the hydroacoustic data was delineated into 3 stratas (pelagic, mid-pelagic, demersal) in which the individuals were counted per strata by sample day; two, the species identified using electroshocking were separated into the area of the water column that the fish typically reside (pelagic, demersal, or both). Fish labeled as having no water column position preference were excluded from the analysis. It was hypothesized that a greater proportion of demersal fish would be present on the reefs. In contrast, the proportion of fish that are found in the pelagic region would be greater on the comparison sites.

Four reproduction guilds were chosen based on Balon's (1975) general categories. Broadcast spawning species were divided into fish that typically have a preference for hard-bottomed areas and fish that have no substrate preference. All nesting species (grass, mud, or gravel) were combined into a single guild because reef substrate is unsuitable for nest construction. Species that seek out shallow, vegetated water in the margins were combined into the category "vegetation preference" because none of the above would typically breed on relatively deep (>2 meters), large rocky areas. The marine spawning American eels *Anguilla rostrata* and Atlantic menhaden *Brevoortia tyrannus* were excluded from the reproductive guild analysis; young of the year fish were also excluded. Analysis was run on sample days that occurred during the spawning season for most fish in the tidal-freshwater James River (March-October). It was hypothesized that fish that preferentially broadcast spawn over rock and cobble would utilize the constructed reefs in greater numbers than nest building species, fish that seek vegetative structure on the margins, or generalist broadcast spawners.

Feeding behavior was divided into six guilds based on distinctive diet choices (Schlosser 1982; Elliot and Dewailly 1995; Matthews 1998). Species were placed into guilds based on what occupied the majority of their diet, based on literature descriptions. Planktivores consume plankton, suspended detritus, and other microscopic organic matter. General carnivores eat other fish as well as invertebrates >25% of the time. Fish that consume primarily invertebrates are labeled as general invertivores (fish <25% of diet). Omnivores diet consist of >25% plant matter and detritus in addition to animal matter. Parasites attach to other fish for sustenance; this guild was occupied only by the sea lamprey *Petromyzon marinus* in this study. Finally, piscivores primarily consume fish (<25% of diet invertebrates or plant matter). All captured fish were included in this analysis, including young of the year individuals; juvenile fish were placed in separate feeding guilds if their feeding habits differed from the adults (Table 3). On marine constructed reef, invertevorous fish attracted by rapidly colonizing invertebrates are initially most drawn to the reefs (Fager 1971; Bohnsack and Sutherland 1985). It was hypothesized that the tidal-freshwater constructed reefs would follow a similar trend, leading to a higher proportion of general invertivores on the reefs than their respective comparison sites.

The CPUE for the hydroacoustic data and the electroshocking data, average target strength, species diversity and richness, the proportions of resident to transient fish, and the proportion of individuals that occupied the water column position, reproductive, and feeding guilds were compared between the reefs and their respective comparison sites. The data were analyzed for significant differences using paired t-tests in JMP 9™. All tests used an alpha rate of 0.08.

The Shapiro-Wilk test for normality determined that overall number of individuals recorded through electroshocking, species richness, electroshocking water column position, reproductive, and feeding guilds were significantly skewed. A natural log transformation was used to normalize the data, thereby meeting parametric assumptions.

# II. Results

## A. Overall Population

The hydroacoustic equipment was utilized for 77 minutes on Reef 1 and 68 minutes on Comparison 1 during 14 sample days. We recorded 7048 fishes inhabiting Reef 1 and 4408 individual fish inhabiting Comparison 1. The highest CPUE for Reef 1 was 348 individuals identified per minute recording (29 June 2011); the highest CPUE for Comparison 1 was 162 per minute (31 August 2011; Figure 5a). The hydroacoustic CPUE was greater at Reef 1 than Comparison 1 ($t_{13}$= 1.50; $p$= 0.08). The majority of individuals recorded by the hydroacoustic device were small in size. The median TS on all of the sites was -58; this translates to roughly 5-10 centimeters long, depending on species (Foote 1987). The electroshocking vessel was run for 149 minutes on Reef 1 and 136 minutes on Comparison 1 during 12 sample days. We did not electroshock alongside the hydroacoustic device on 24 February 2011 and 24 January 2012 because water temperatures were below 6 degrees Celsius, too low for the electroshocking unit to function efficiently. A total of 892 individuals in 15 species were identified on Reef 1 and 959 individuals in 14 species were identified on Comparison 1. The most common species at all sites were blue catfish *Ictalurus furcatus* (54% of total individuals), blueback herring (12%), gizzard shad (11%), and inland silverside *Menidia beryllina* (10%). The highest CPUE on Reef 1 was 27 individuals per minute electroshocking (31 August 2011); the highest CPUE on Comparison 1 was 26 individuals (31 August 2011; Table 4; Figure 6c). Electroshocking CPUE was not significantly greater at Reef 1 than Comparison 1 ($t_{13}$=2.6, $p$ =0.99), but CPUE was significantly greater at Comparison 1 than Reef 1 ($p$ =0.01). TS, species diversity, and richness were similar between Reef 1 and Comparison 1 (Table 4).

The hydroacoustic equipment was utilized for 74 minutes on Reef 2 and 68 minutes on Comparison 2 during 11 sample days. We recorded 5623 fishes inhabiting Reef 2 and 5468 fishes inhabiting Comparison 2. The highest CPUE for Reef 2 was 212 individuals per minute (27 October 2011); the highest CPUE for Comparison 2 was 181 individuals per minute (7 April 2011; Figure 6b). The electroshocking vessel was run for 124 minutes on Reef 2 and 125 minutes on Comparison 2 during 10 sample days. The electroshocking unit was not run at the same time as the acoustic device on January 24th, 2012 because of low water temperatures. A total of 471 individuals from 14 species were identified on Reef 2 and 1330 individuals from 13 species on Comparison 2. The highest CPUE for Reef 2 was 12 individuals per minute electroshocking (4 August 2011); the highest CPUE for Comparison 2 was 47 individuals per minute electroshocking (31 August 2011; Figure 6d). Overall hydroacoustic and electroshocking CPUE, TS, and species diversity and richness were similar between Reef 2 Comparison 2 (Table 4).

B. Residency

The proportion of resident fish to transient fish was greater on Reef 1 than Comparison 1 ($t_{13}$= 1.68; $p$= 0.06), which also resulted in the proportion of transient fish to resident fish to be greater on Comparison 1 than Reef 1 ($t_{13}$= 1.68; $p$= 0.06). No differences were found between Reef 2 and Comparison 2 (Table 4). Resident fish captured in this study were dominated by non-native blue catfish (92%). Excepting non-native species, most of the individuals captured were diadromous (98% of all native individuals caught via electroshocking).

C. Water Column Position

Reef 1 had a greater proportion of fish that are typically demersal (electroshocking data) than Comparison 1 ($t_{13}$= 1.54; $p$= 0.07). Comparison 2 had a greater proportion of pelagic fish within both the electroshocking data ($t_{11}$= 1.61; $p$= 0.07) and the hydroacoustic data ($t_{11}$= 1.63; $p$= 0.07) than Reef 2 (Table 4, Figure 7a-b). There was not a significantly greater proportion of mid-pelagic fish (hydroacoustics) on Comparison 2 than Reef 2 ($t_{10}$ =2.87; $p$ =0.99) as had been hypothesized, but a greater proportion of mid-pelagic fish was found on Reef 2 than Comparison 2 ($p$ =0.01). Mid-pelagic fish were the most represented in the hydroacoustic data (Figure 7a), and pelagic fish were the most abundant in the electroshocking data (Figure 7b).

D. Reproductive and Feeding Guilds

Substrate difference of the reefs may have attracted some species more than their respective comparison sites. There was a significantly greater proportion broadcast spawners preferring hard substrate on Reef 2 than Comparison 2 ($t_8$ =2.17, $p$ =0.03). Both Comparison 1 ($t_9$ =2.58, $p$ =0.02) and Comparison 2 ($t_8$ =2.09, $p$ =0.04) had a greater proportion of fishes that broadcast spawn without a substrate preference than their respective reefs. There was no difference in percentage of fishes that prefer vegetative structure between Comparison 2 than Reef 2 ($t_8$ =1.84, $p$ =0.95), though the amount of fish that seek vegetative structure for spawning was significantly greater on Reef 2 than Comparison 2 ($p$=0.05). There was a significantly greater proportion of nest building fish on Comparison 1 than Reef 1 ($t_9$ =2.11, $p$ =0.03). The species that broadcast spawn over rocky substrate were gizzard shad (48% of all hard substrate spawning fish), blueback herring (31%), threadfin shad (19%), and white perch (2%). Fishes that broadcast spawn over hard substrate and nest building fish were the most represented at all sites (Table 4; Figure 7c). There were no significant differences between both reefs and their comparison sites for any of the feeding guilds (Tables 4). Omnivores and piscivores were the most common at all sites (Figure 7d).

E. Gillnetting, Trawling, and Egg Mats

Gillnetting occurred on Reef 1 on three dates in 2011 (23 May, 2 June, and 15 June) and one date in 2012 (25 January). Comparison 1 was netted the same days, except 23 May 2011. Reef 2 was gillnetted twice during 2011 (23 May and 15 June) and once during 2012 (26 January). Comparison 2 was netted on the same dates except 23 May 2012. Gillnetting caught several species that were not captured by electroshocking: the shorthead redhorse *Moxostoma macrolepidotum*, Atlantic menhaden *Brevoortia tyrannus*, and the black crappie *Pomoxis nigromaculatus*, as well as the only young of the year striped bass.

Trawling only occurred on Reef 1 on 20 May 2011 and 18 January 2012. Trawling over the reefs was relatively ineffective because the net could easily be caught on the rocks and trawling the perimeter was too brief to provide many fish. Trawling did produce a black crappie and several hogchockers, two species that were not captured by electroshocking. Because the gillnetting and trawling data sets were sparse and the sample days did not coincide with the acoustic and electroshocking sample days, no statistics were run. The gillnetting and trawling data was of interest because these two methods caught several demersal species that could be picked up by the acoustic instrument.

The egg mats successfully captured several different types of fish eggs on the reefs. Inland silverside, white perch, and spottail shiner *Notropis hudsonius* eggs were found on the egg mats at both constructed reefs. The mats attracted a large amount of invertebrates, though this may have been caused by the porous nature of the buffer pads providing ample hiding space.

## IV. Discussion

Our objective was to determine if constructed reefs are an effective restoration method for tidal-freshwater rivers with limited clean rocky spawning habitat. The results suggest that the constructed reefs are potentially attracting a more abundant and different community of fish than the nearby silted areas. Fish abundance and the number of resident and demersal fish were more abundant on the reefs as well as fish that broadcast spawn over hard substrate, while fish that broadcast spawn with no substrate preference, transient, and pelagic fish were more numerous on the comparison sites.

### A. Overall Abundance, Diversity, and Fish Size

The hydroacoustic result for Reef 1 ($p$=0.08) suggested the trend that more individuals were on the reef than Comparison 1, despite electroshocking results showing more individuals on Comparison 1 ($p$= 0.01, Figure 6). The electroshocking data is biased based on the size of fish detected, while the hydroacoustic unit accurately measures most fish that are within the acoustic cone at the time of data collection, making the hydroacoustic results more accurate in terms of overall abundance (Simmonds and MacLennan 2005). Seasonally, the constructed reefs had a higher abundance during the spring and fall, which is likely caused by diadromous species spawning migrations (Figure 6a-b). Species diversity was not significantly greater at the constructed reefs than their respective comparison sites (Reef 1: $p$= 0.53; Reef 2: $p$= 0.43) and mean diversity was low at all of the sites (Reef 1= 0.62, Comparison 1= 0.63, Reef 2= 0.77, Comparison 2= 0.78). This was likely influenced by the dominance of blue catfish, gizzard shad, blueback herring, and inland silversides. The majority of the individuals captured during this study were members of these four species (87%), while species richness was 15 at Reef 1, 14 at Comparison 1, 14 at Reef 2, and 13 at Comparison 2.

The average target strength (TS) of fish recorded by the hydroacoustic equipment was small, roughly translating to a 5-10 centimeter long fish. Using Foote's (1987) equation based on swimbladder type and size, approximate TS ranges were calculated for 24 James River species (Physostomes: TS=20log(length)-71.9; Physoclists: TS=20Log(length)-67.4; Table 5). Though this equation was based on a 38 kHz transducer, the results were used to rank these species from smallest to largest and fit them within TS recorded in this study. Small fish species in question could be bay anchovies *Anchoa mitchilli*, mummichogs *Fundulus heteroclitus*, inland silversides, and/or spottail shiners *Notropis hudsonius*, all species captured by the electroshocking vessel that were included in the smallest TS size class (Table 5). Small individuals could also be comprised of young of the year fish for species that breed in that area, depending on life history traits and spawning patterns of the adults. Mean target strengths were similar between the four sites, indicating that the average fish was not larger on the constructed reefs than their respective comparison sites (Table 4). The constructed reefs may still be acting as nurseries though; small fish hiding in rock crevices would not be detected by the hydroacoustic equipment.

B. Residency

There was a greater proportion of resident fish on Reef 1 ($p$=0.06), and in correlation a greater proportion of transient fish on Comparison 1 ($p$= 0.06); these results reflect a similar trend to most marine constructed reefs, with more resident species on the constructed reefs and more transient species off the constructed reefs (Walsh 1985; Seaman and Sprague 1991; Bohnsack et al. 1994; Golani and Diamant 1995; Leitão et al. 2008). This suggests that there is a resident community that stays year round on the constructed reefs.

The species composition in the James River has been affected by species introduced as game fish over the past several decades, including large apex predators such as the blue catfish and flathead catfish *Pylodictis olivaris* (MacAvoy et al. 2000; Moser 2002). Native resident species are being out-competed by introduced species in the tidal-freshwater James River (Viverette et al. 2007). Resident species captured in this study were almost entirely non-native fish (98%) and the majority of residents were highly invasive blue catfish (92%). Changes in the fish assemblage in the tidal-freshwater James River by introduced species may have altered the resident fish community on the constructed reefs; native resident fish that were abundant prior to non-native intrusion may now be too reduced to effectively colonize the rocky substrate.

C. Water Column Position Preference

The results show a trend of individual fish typically residing lower in the water column on the constructed reefs and higher in the water column on the comparison sites. Reef 1 had a greater proportion of demersal fish (electroshocking: $p$ =0.07), though the median proportions of demersal fish on Reef 1 and Comparison 1 were small (<1%; Figure 7b). In contrast, Comparison 2 had a greater proportion of pelagic fish (electroshocking $p$ =0.07; hydroacoustics $p$ =0.07; Table 4, Figure 7a-b). Mid-pelagic fish were more represented on Reef 2 than Comparison 2 ($p$ =0.01), which is opposite from what we expected; the structure of the strata delineations may have resulted in a portion of demersal fish being registered within this layer. Additionally, some demersal species were not detected as abundantly as pelagic fish because electroshocking is biased toward fish higher in the water column (Johnson et al. 2008). Gillnetting and trawling captured a shorthead redhorse and several hogchokers, both demersal species that were not captured by electroshocking. Therefore, water column position results are likely skewed towards pelagic and mid-pelagic fish.

D. Reproductive Guilds

The constructed reefs were created to increase the area of hard-bottom spawning habitat available to resident and anadromous fishes. A greater proportion of fish that seek out rocky substrate to spawn were attracted to Reef 2 ($p$ =0.03), while a greater proportion of fish that broadcast spawn with no substrate preference were found on Comparison 1 ($p$ = 0.02) and Comparison 2 ($p$= 0.04). The species that broadcast spawn over rock and gravel may have been attracted to Reef 2 for spawning.

Four species (gizzard shad, threadfin shad, white perch, and blueback herring) that broadcast spawn over hard substrate exhibit some migratory behavior in the tidal-freshwater James River

(Table 3). Both gizzard shad and blueback herring were abundant in this study (12% and 11% of overall fish abundance, respectively); only blue catfish were more represented overall (54%). The four hard substrate broadcast spawning species do not normally reside on rocky substrate. Gizzard shad and threadfin shad are open-water fish typically found near the surface in sluggish waters with no salinity (Hubbs and Lagler 1943; Lambou 1965, Jenkins and Burkhead 1994). White perch are demersal feeders that prefer fine substrate with little cover in areas with salinity ranging from 5-13% (Mansueti 1964). Blueback herring are highly migratory, moving upstream in deep lotic tidal-freshwater with firmer substrate such as in the main river channel (Hildebrand and Schroeder 1928; Scott and Crossman 1973; Loesch and Lund 1977; Mullens et al. 1986). This is of particular interest because these fish would have to stray farther from their migration path to reach Reef 2, since Comparison 2 is in actuality closer to the channel (Figure 2).

Hard substrate broadcast spawning fish were most proportionally abundant in the spring and fall (Figure 8); these are peak spawning times for many James River fishes (Jenkins and Burkhead 1994). Gizzard shad and threadfin shad spawn in spring and summer near the surface, preferring rocky substrate where their eggs can adhere until they hatch (Miller, 1960; Lambou 1965); during the fall and winter they may migrate to the more brackish water in the Chesapeake Bay (Jones et al. 1978; Jenkins and Burkhead 1994). In mid-spring blueback herring spawn demersally near clean, rocky substrate and have adhesive eggs that harden and detach in turbid waters (Loesch and Lund 1977; Mullens et al. 1986; Jenkins and Burkhead 1994). White perch migrate to tidal-freshwaters in the spring to seek out rocky substrate for spawning; their eggs are initially sticky and will adhere to submerged objects in slow moving water, but harden quickly in tidally influenced lotic waters (Mansueti 1964). Though production cannot be assumed based on attraction, higher proportions of these species on the constructed reefs suggests that these fish were drawn to the reefs for spawning.

Gizzard shad, threadfin shad, blueback herring, and white perch are ecologically and commercially important species. Gizzard shad, threadfin shad, and blueback herring are typically filter feeders consuming plankton and copepods, though adults will consume insects and plants; white perch are general carnivores eating insect larvae and other fish (Jenkins and Burkhead 1994). All four species are common prey for fish eating birds and large piscivorous fish, including striped bass, blue catfish, and longnose gar *Lepisosteus osseus* (Miller 1960; Alsop and Forney 1962; Lambou 1965; Tyus 1974; Bath and O'Connor 1982). Gizzard shad and threadfin shad are a minor commercial fish, usually used as bait for larger predatory fish (Jenkins and Burkhead 1994). White perch are important commercial and recreational species that are heavily harvested for both human consumption and as a baitfish (Jones 1982). There is a large historic commercial fishery for blueback herring, primarily for their roe; they are a popular recreational fish as well (Joseph and Davis 1965). Recently, a moratorium on fishing blueback herring has been placed because of damage done to the population by loss of habitat, habitat alteration, and impaired water quality; blueback herring are being reviewed to potentially be listed under the United States Endangered Species Act as threatened (NMFS, 2011). Creating spawning habitat for these important species benefits the ecosystem as a whole, as well as supporting anthropogenic interests.

The results that compared the proportion of nest building species between the reefs and their comparison sites as well as the proportion of fish that prefer shallow, vegetated areas for spawning were unclear. Nest building species were proportionally more abundant on Reef 2 than Comparison 2 ($p$= 0.06), but also proportionally greater on Comparison 1 than Reef 1 ($p$ =0.03). The greater proportion of nest building fish on the reefs was a spurious result caused by the large number of residential introduced catfish (blue catfish, channel catfish, and flathead catfish; 99% of nest building fish); these fish are likely not spawning on the reefs because the substrate is not suitable for nest building, though they may use the comparison sites for spawning (Jenkins and Burkhead 1994). They could be drawn to the reefs for feeding (potentially on fish that are on the constructed reefs for spawning) though no differences were discerned between the constructed reefs versus their respective comparison sites in regards to the feeding guild proportions (MacAvoy et al. 2000). Similarly, the proportion of fish that prefer vegetative structure to spawn on was greater on Reef 2 than Comparison 2 ($p$ =0.05) but also greater on Comparison 1 than Reef 1 ($p$ =0.09). The four species that were in this guild (common carp *Cyprinis carpio*, longnose gar, mummichog *Fundulus heteroclitus*, and inland silverside) were not on the reefs or the comparison sites for spawning because of the lack of vegetative cover as well as the relative depth of the sites (these fish prefer to spawn in waters 1-2 meters deep) provided inappropriate conditions (Jenkins and Burkhead 1994). The differences in proportions of nest building fish and vegetated preference fish between the constructed reefs and their comparison sites were not in relation to reproductive substrate preferences and therefore were not of interest for this study.

E. Feeding Guilds

Feeding guilds were not significantly different between the reefs and their comparison sites (Table 4). James River fishes are mostly trophic generalists, consuming what their gape size will allow (Jenkins and Burkhead 1994; Smock et al. 2005). Because of the relative youth of the constructed reefs, the invertebrate community may not be fully stabilized; as the amount of invertebrates increases, so may the amount of invertivorous fish (Bohnsack and Sutherland 1985). Alternatively, fish may be attracted to the reefs to consume young of the year fish, but several years of detailed gut analysis of fish on and off the reefs post-spawning season would be needed to determine this. If this project were extended several years, than a distinction between the feeding guilds of the constructed reefs and their respective comparison sites may be more evident.

F. Future Priorities

Conclusive evidence that Atlantic sturgeon are spawning on the constructed reefs has not been documented, but the fish have been found near the reefs. Despite the difficulties in determining species with hydroacoustic equipment, there was one recorded fish that was identified to species. On 27 October 2011, one large (-20 dB) demersal fish on Comparison 2 was determined—with a great deal of likelihood—to have been a passing Atlantic sturgeon (Figure 9). This conclusion was based on a number of indicators, primarily that the TS of the specimen observed that day corresponded to the study done by Reine et al. (2010) on TS ranges for Atlantic sturgeon in the James River with identical equipment. In further support, the water column position and time of year matched the preference for the species. This was the only hydroacoustically recorded fish in this study that may be classified as an Atlantic sturgeon. At present, there is discussion of building a third reef. Creating a constructed reef system with several reefs in close proximity is beneficial; sturgeon are more likely to use constructed spawning reefs if they cover a greater area and are closer to existing breeding grounds (Faucher 1999; Faucher and Abbot 2001; Manny et al. 2004; Kennedy et al. 2009).

As the constructed reef system grows within the James River, the focus needs to be on ideal placement of the reefs. Sedimentation of the constructed reefs is of concern because of the great amount of silt in the James River system. The two constructed reefs in this study have already been affected by siltation (G. Austin VCU, personal communication). If the constructed reefs become silted in one or two years, their effectiveness for benefiting spawning populations will be reduced. Accurate sedimentation rates on potential reef construction sites are needed to determine how quickly the reefs will be covered. In addition to sedimentation information, detailed spawning information is needed for the species of interest. The salinity on the current constructed reefs may be too high (>0.05 ppt) during the late summer months when some Atlantic sturgeon spawn (Van Eenennaam et al. 1996; M. Balazik VCU, personal communication). Lack of salinity intrusion may be the key to attracting other native species as well; gizzard shad and blueback herring require little to no salinity for successful spawning (Hubbs and Lagler 1943; Lambou 1965; Scott and Crossman 1973; Mullens et al. 1986). Constructing a reef further upstream will make it less susceptible to salinity intrusion, which may increase the reefs attraction to Atlantic sturgeon and other species that require freshwater.

Based on the results of this study, constructed reefs are attracting species within a tidal-freshwater river that has limited clean, rocky substrate. Constructed reefs alone will likely not greatly improve the fish community, though. Native diadromous species are being out-competed by introduced species, in addition to stress from over-fishing, habitat alteration, pollution, and sedimentation (Forester and Reagan 1977; Loesch and Atran 1994; Viverette et al. 2007). Adding suitable spawning and nursery grounds may increase production for these species, but the survival of their eggs and young is dependent on clean waters, dam removal, riparian buffers, and invasive species control.

# V. Conclusions

The purpose of this study was to determine if constructed reefs in a tidal-freshwater river attracted a different fish community than nearby silted areas. The results indicated that the constructed reefs may be attracting more resident and demersal fish as well as species that utilize rocky substrate for spawning. Expanding this study on a temporal, diurnal, and spatial scale may find additional differences between the constructed reefs and comparison sites. Using constructed reefs in a tidal-freshwater river as a restoration device is still a new method; additional research is needed to determine if constructed reefs are an appropriate restoration method for these unique systems.

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Appendix A. Tables

Table 1. Constructed reef research locations physical characteristics

| | Tropical Marine Systems | Temperate Lake systems | Tidal-Freshwater Systems |
|---|---|---|---|
| **Temperature** | Warm Year-Round | Seasonal Temperature Fluctuations | Season Temperature Fluctuations |
| **Salinity** | Nonvariant Salinity | No Salinity | Seasonal Salinity Variances |
| **Visibility** | Typically Clear Visibility | Visibility Dependant on Individual Lake | Typically Murky Waters |
| **Species Diversity** | Great Diversity of Species | Limited by Fluvial Inputs | Riverine, Diadromous, and Estuarine Species |
| **Reef Residency** | Mostly Reef Resident Species | Mostly Reef Visitor Species | Undetermined |
| **Tidal Influence** | Tidal Influence (shallow reefs) | Nontidal, Slow Moving Waters | Tidal Influence |

Table 2. Visual Analyzer$^{TM}$ 4.2 settings

| | |
|---|---|
| **Echo Recognition** | |
| Echo Threshold | -0.65 |
| Correlation Factor | 0.95 |
| Min Pulse Width Factor | 0.75 |
| Max Pulse Width Factor | 2 |
| End Point Criteria (dB) | -6 |
| **Reports/Strata** | |
| # of Strata | 3 |
| # of Reports | 5 |
| **Analysis Limits** | 0.5 m to deepest bottom depth |
| **Target Strength Distribution** | |
| Max Target Strength | -20 |
| # of Bins | 23 |
| Bin Height (dB/bin) | 2 |
| Beam Pattern Threshold (dB) | -4 |

Table 3. Species specific information. Water Column Position (D= demersal, P= pelagic); Residency (R= Resident, T=Transient); Reproductive Guilds (BD= General Broadcasters, BDH= Broadcasters, hard-bottom preference, NB= Nest Builders, VG= Vegetation Preference); Feeding Guild (PL= Planktivore, GI= General Invertivore, GC= General Carnivore, OM= Omnivore, PA= Parasite, PI= Piscivore); Commercial Value (NA= none, R= Recreational, HF= Historic Fishery, SC= Secondary Commercial, PC= Primary Commercial); and Locality (N= Native and I=Introduced).

| Species | Water Column Position | Residency | Reproductive guilds | Feeding Guild: Juveniles | Feeding Guild: Adults | Commercial value | Native/ Introduced |
|---|---|---|---|---|---|---|---|
| *Petromyzon marinus* | D | T | NB | FF | PA | SC | N |
| *Acipenser oxyrhinchus* | D, P | T | BH | GI | GI | HF | N |
| *Lepisosteus osseus* | P | R | VG | GC | PI | R, SC | N |
| *Anguilla rostrata* | D | T | BD | GC | GC | R, PC | N |
| *Dorosoma cepedianum* | P | T | BDH | FF | OM | R, SC | N |
| *Dorosoma petenense* | P | T | BDH | FF | OM | R, SC | N |
| *Alosa aestivalis* | P | T | BDH | FF | GI | R, PC | N |
| *Alosa mediocris* | P | T | BD | FF | GC | SC | N |
| *Alosa sapidissima* | P | T | BD | FF | FF | R, PC | N |
| *Brevoortia tyrannus* | P | T | BD | FF | FF | PC | N |
| *Anchoa mitchilli* | P | T | BD | FF | OM | SC | N |
| *Cyprinis carpio* | D | R | VG | OM | OM | R, PC | I |
| *Notropis hudsonius* | D, P | R | BD | OM | OM | NA | N |
| *Carpiodes cyprinus* | D | R | BD | OM | OM | SC | N |
| *Moxostoma macrolepidotum* | D | R | BDH | GI | GI | R | N |
| *Ictalurus furcatus* | D,P | R | NB | GC | PI | R, PC | I |
| *Ictalurus punctatus* | D | R | NB | GC | OM | R, PC | I |
| *Ameiurus catus* | D | R | NB | GI | OM | R, HF | N |
| *Pylodictis olivaris* | D | R | NB | GC | PI | R | I |
| *Menidia beryllina* | P | T | VG | FF | OM | NA | N |
| *Fundulus heteroclitus* | D | R | VG | GI | GC | NA | N |
| *Morone americana* | D | T | BDH | GC | GC | R, SC | N |
| *Morone saxatilis* | P | T | BD | GC | PI | R, PC | N |
| *Pomoxis nigromaculatus* | D,P | R | NB | GC | PI | R, SC | N |
| *Micropterus salmoides* | D, P | R | NB | GC | GC | R | I |
| *Trinectes maculatus* | D | T | BD | GI | GI | NA | N |

Table 4. Paired t-test results between the reefs and their respective comparison sites. Median and Interquartile Range (IQR) listed for data that was not normally distributed. Mean and Standard Deviation (SD) listed for data that was normally distributed. Numbers with an asterisk (*) indicate significant findings according to $\alpha$ =0.05. Normality determined by the Shapiro-Wilk test in JMP 9$^{TM}$.

| | | | | Reef 1 | | Comparison 1 | |
|---|---|---|---|---|---|---|---|
| **Reef 1: Skewed distribution** | **t (13)** | **p-value** | **N** | **Median** | **IQR** | **Median** | **IQR** |
| Shocking CPUE | 2.60 | 0.99 | 14 | 3 | [0-8] | 3.34 | [0-6] |
| Target Strength Average | 1.02 | 0.16 | 14 | -58 | [-59--57] | -58 | [-60---60] |
| **Water Column Position Electroshocking** | | | | | | | |
| Demersal | 1.54 | 0.07 | 14 | 0 | [0-0.07] | 0 | [0-0.02] |
| Pelagic | 0.36 | 0.36 | 14 | 0.51 | [0.06-0.97] | 0.51 | [0.13-0.94] |
| **Feeding Guilds** | | | | | | | |
| Planktivores | 0.10 | 0.46 | 14 | 0 | [0-0] | 0 | [0-0.02] |
| General Carnivores | 0.70 | 0.75 | 14 | 0 | [0-0] | 0 | [0-0.01] |
| General Invertivores | 1.71 | 0.94 | 14 | 0 | [0-0.10] | 0 | [0-0.20] |
| Omnivores | 0.12 | 0.45 | 14 | 0.06 | [0-0.94] | 0.16 | [0-0.55] |
| Parasites | 1.00 | 0.17 | 14 | *No parasites | | 0 | [0-0] |
| Piscivores | 1.38 | 0.10 | 14 | 0.37 | [0-0.66] | 0.11 | [0-0.48] |
| **Reproduction Guilds** | **t (8)** | | | | | | |
| Broadcaster, no preference | 2.58 | 0.02* | 9 | 0 | [0-0] | 0.02 | [0-0.03] |
| Broadcaster, hard substrate | 0.27 | 0.60 | 9 | 0.34 | [0.04-0.64] | 0.22 | [0.13-0.81] |
| Nest Builder | 2.11 | 0.03* | 9 | 0.42 | [0.19-0.81] | 0.28 | [0.03-0.71] |
| Vegetation Preference | 1.45 | 0.09 | 9 | 0.04 | [0-0.05] | 0.03 | [0-0.17] |
| **Reef 1: Normal distribution** | **t (13)** | **p-value** | **N** | **Mean** | **SD** | **Mean** | **SD** |
| Acoustics CPUE | 1.50 | 0.08 | 14 | 95 | 99 | 61 | 52 |
| Diversity | 0.06 | 0.53 | 14 | 0.62 | 0.51 | 0.63 | 0.53 |
| Richness | 0.73 | 0.76 | 14 | 3 | 3 | 4 | 3 |
| Resident | 1.68 | 0.06 | 14 | 0.35 | 0.35 | 0.28 | 0.33 |
| Transient | 1.68 | 0.06 | 14 | 0.51 | 0.39 | 0.58 | 0.40 |
| **Water Column Position Hydroacoustics** | | | | | | | |
| Pelagic | 0.78 | 0.78 | 14 | 0.25 | 0.25 | 0.19 | 0.21 |
| Mid-Pelagic | 0.81 | 0.78 | 14 | 0.46 | 0.19 | 0.41 | 0.23 |
| Demersal | 0.64 | 0.73 | 14 | 0.29 | 0.10 | 0.33 | 0.24 |

Table 4 continued.

| | | | | Reef 2 | | Comparison 2 | |
|---|---|---|---|---|---|---|---|
| **Reef 2: Skewed distribution** | **t (10)** | **p-value** | **N** | **Median** | **IQR** | **Median** | **IQR** |
| Shocking CPUE | 0.86 | 0.80 | 11 | 1 | [0-6] | 3 | [0-7] |
| Target Strength Average | 1.01 | 0.83 | 11 | -58 | [-60--60] | -58 | [-60--56] |
| **Water Column Position Electroshocking** | | | | | | | |
| Demersal | 0.89 | 0.39 | 11 | 0.10 | [0-0.18] | 0.07 | [0-0.14] |
| Pelagic | 1.61 | 0.07 | 11 | 0.29 | [0.21-0.5] | 0.47 | [0.13-0.83] |
| **Feeding Guilds** | | | | | | | |
| Planktivores | 1.32 | 0.11 | 11 | 0 | [0-0] | 0 | [0-0] |
| General Carnivores | 0.68 | 0.26 | 11 | 0 | [0-0] | 0 | [0-0] |
| General Invertivores | 1.00 | 0.83 | 11 | *No general invertivores | | 0 | [0-0] |
| Omnivores | 0.36 | 0.64 | 11 | 0.37 | [0.22-0.5] | 0.28 | [0.12-0.43] |
| Parasites | - | - | 11 | *No parasites | | *No parasites | |
| Piscivores | 0.18 | 0.43 | 11 | 0.39 | [0-0.7] | 0.45 | [0-0.69] |
| **Reproduction Guilds** | **t (7)** | | | | | | |
| Broadcaster, no preference | 2.09 | 0.04 | 8 | 0 | [0-0.01] | 0.03 | [0-0.50] |
| Broadcaster, hard substrate | 2.17 | 0.03 | 8 | 0.26 | [0.18-0.57] | 0.24 | [0.07-0.24] |
| Nest Builder | 1.82 | 0.94 | 8 | 0.60 | [0.41-0.74] | 0.30 | [0.09-0.64] |
| Vegetation Preference | 1.84 | 0.95 | 8 | 0.06 | [0.01-0.20] | 0.01 | [0-0.12] |
| **Reef 2: Normal distribution** | **t (10)** | **p-value** | **N** | **Mean** | **SD** | **Mean** | **SD** |
| Acoustics CPUE | 0.24 | 0.40 | 11 | 85 | 79 | 81 | 57 |
| Diversity | 0.17 | 0.43 | 11 | 0.78 | 0.56 | 0.77 | 0.55 |
| Richness | 0.86 | 0.80 | 11 | 4 | 3 | 4 | 3 |
| Resident | 0.20 | 0.58 | 11 | 0.40 | 0.34 | 0.42 | 0.36 |
| Transient | 1.31 | 0.11 | 11 | 0.42 | 0.35 | 0.49 | 0.37 |
| **Water Column Position Hydroacoustics** | | | | | | | |
| Pelagic | 1.63 | 0.07 | 11 | 0.19 | 0.18 | 0.28 | 0.22 |
| Mid-Pelagic | 2.87 | 0.99 | 11 | 0.49 | 0.14 | 0.36 | 0.15 |
| Demersal | 0.85 | 0.79 | 11 | 0.33 | 0.13 | 0.36 | 0.15 |

Table 5. Target strength assignments for 24 species of fish in the James River. Size (cm) indicates adult size range. Size rank lists the smallest species captured to the largest. Size class places species in relative target strength ranges based on swimbladder type and size. Position labels species by typical water column position.

| Species | Size (cm) | Size Rank | Size Class | Target Strength (dB) | Position |
|---|---|---|---|---|---|
| *Fundulus heteroclitus* | 4-7 | 3 | 1 | -62 to -64 | Demersal |
| *Moxostoma macrolepidotum* | 20-35 | 9 | 3 | -50 to -54 | Demersal |
| *Morone americana* | 12.5-25 | 10 | 3 | -50 to -54 | Demersal |
| *Ameiurus catus* | 20-45 | 11 | 4 | -44 to -48 | Demersal |
| *Carpiodes cyprinus* | 25-40 | 12 | 4 | -44 to -48 | Demersal |
| *Anguilla rostrata* | 22-100 | 17 | 5 | -38 to -42 | Demersal |
| *Cyprinis carpio* | 35-70 | 18 | 5 | -38 to -42 | Demersal |
| *Pylodictis olivaris* | 40-90 | 19 | 6 | -32 to -36 | Demersal |
| *Morone saxatilis* | 30-90 | 22 | 6 | -32 to -36 | Demersal |
| *Acipenser oxyrhinchus* | 88-200 | 24 | 7 | -20 to -24 | Demersal |
| *Anchoa mitchilli* | 4-4.5 | 1 | 1 | -62 to -64 | Pelagic |
| *Dorosoma petenense* | 7.5-17.5 | 4 | 2 | -56 to -60 | Pelagic |
| *Menidia beryllina* | 6 -13 | 5 | 2 | -56 to -60 | Pelagic |
| *Dorosoma cepedianum* | 7.5-35 | 6 | 3 | -50 to -54 | Pelagic |
| *Alosa aestivalis* | 15-25 | 7 | 3 | -50 to -54 | Pelagic |
| *Brevoortia tyrannus* | 18-32 | 8 | 3 | -50 to -54 | Pelagic |
| *Alosa mediocris* | 28.5-45 | 14 | 4 | -44 to -48 | Pelagic |
| *Alosa sapidissima* | 35-55 | 15 | 5 | -38 to -42 | Pelagic |
| *Lepisosteus osseus* | 67-115 | 23 | 6 | -32 to -36 | Pelagic |
| *Notropis hudsonius* | 6-9 | 2 | 1 | -62 to -64 | Either |
| *Pomoxis nigromaculatus* | 10-40 | 13 | 4 | -44 to -48 | Either |
| *Ictalurus punctatus* | 30-70 | 16 | 5 | -38 to -42 | Either |
| *Micropterus salmoides* | 23-65 | 20 | 6 | -32 to -36 | Either |
| *Ictalurus furcatus* | 50-90 | 21 | 6 | -32 to -36 | Either |

Appendix B. Figures

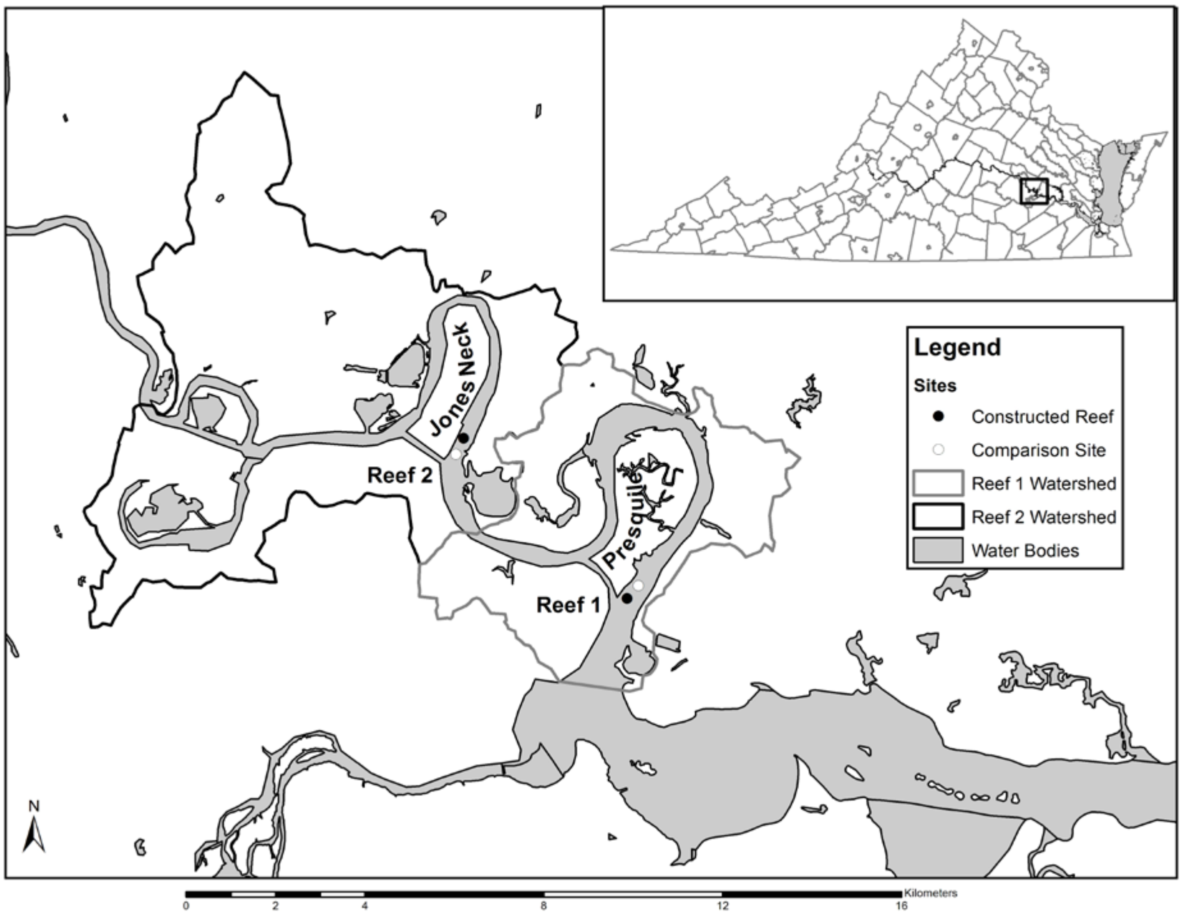


Figure 1. Site locations and watersheds

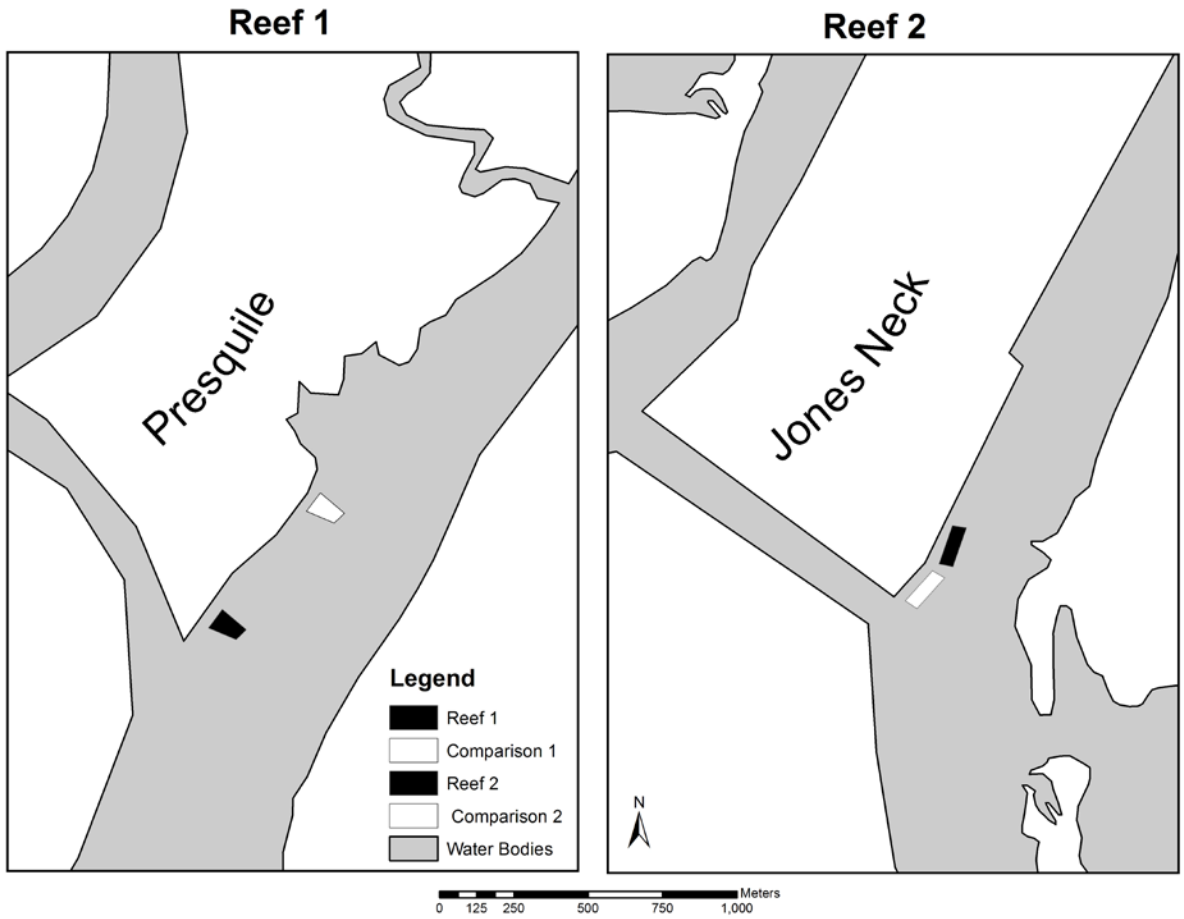

Figure 2. Shape, size, and relative location of the constructed reefs and their respective comparison sites

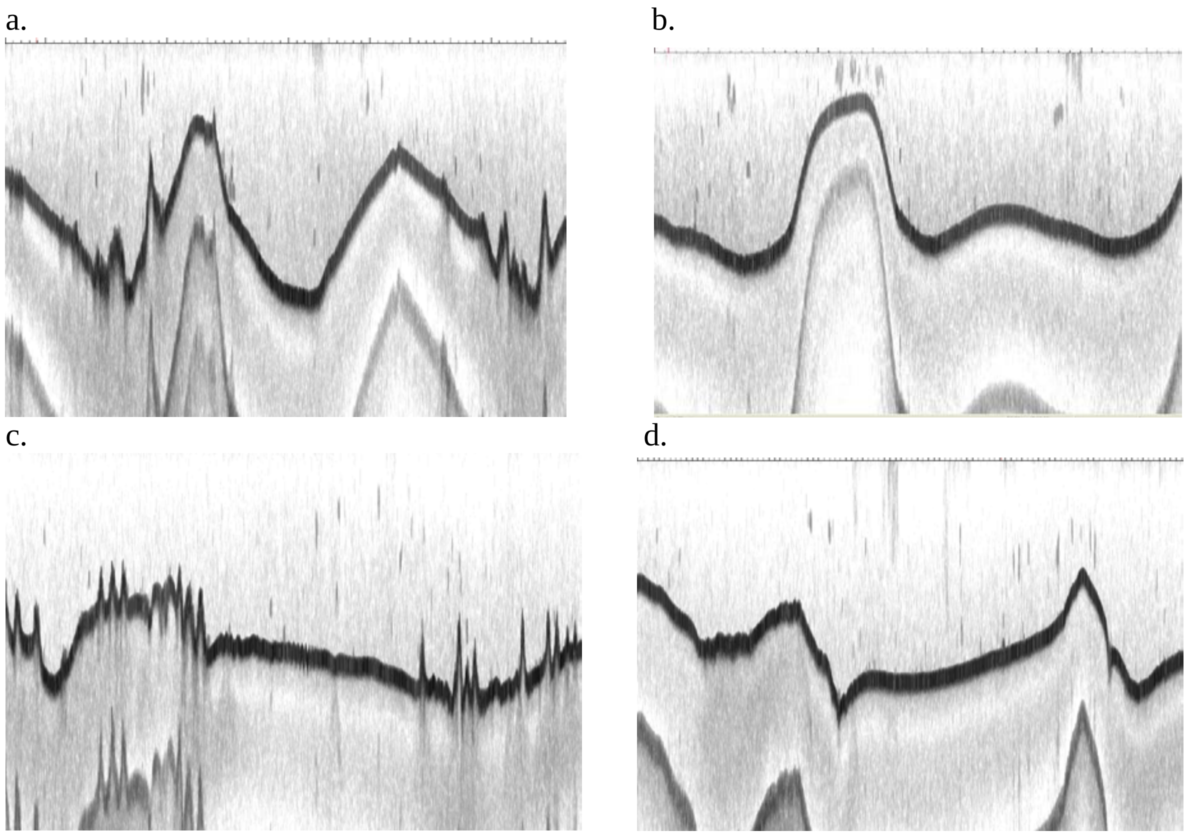


Figure 3. Hydroacoustic mapping differences in bottom structure between the reefs and their respective comparison sites. From 09/29/2011. a. Reef 1. b. Comparison 1. c. Reef 2. d. Comparison 2.

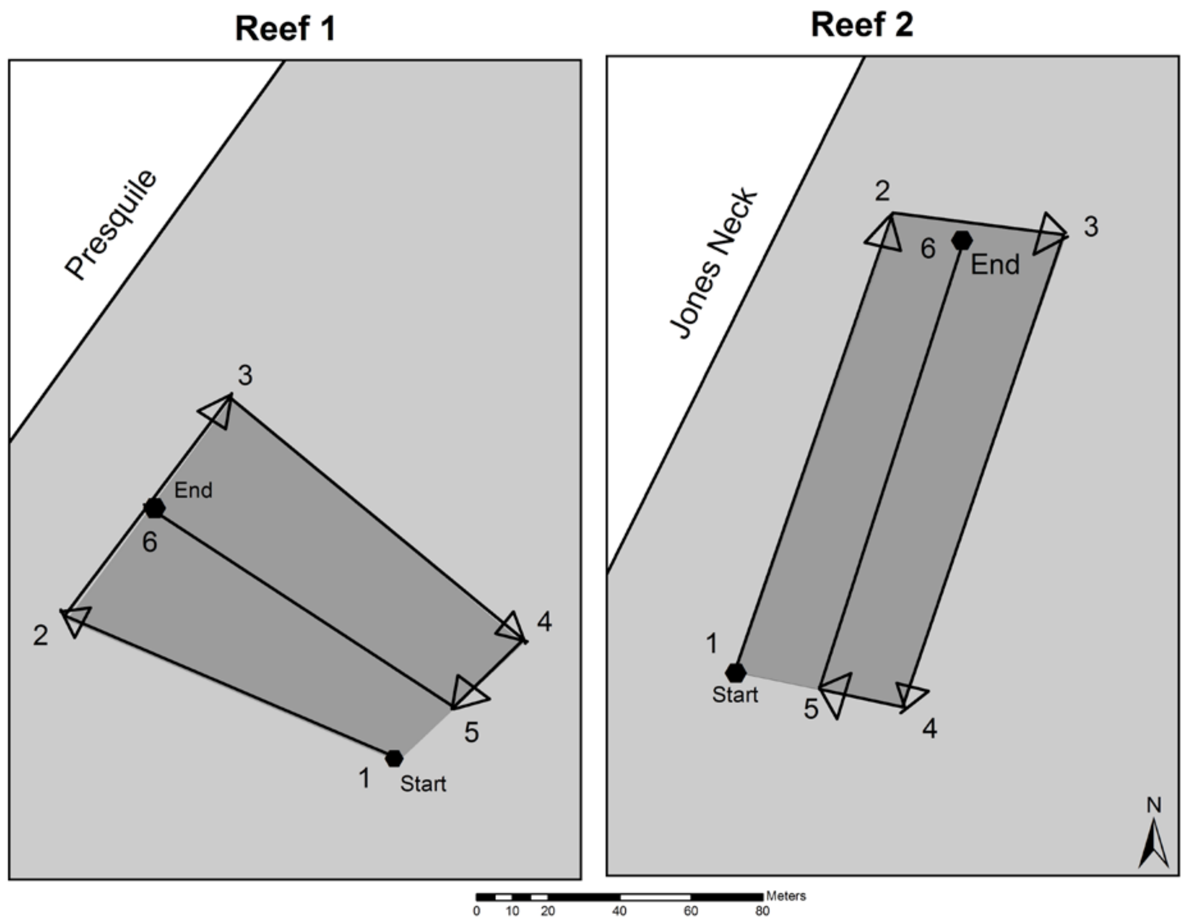


Figure 4. Path of boat while running the hydroacoustic equipment.

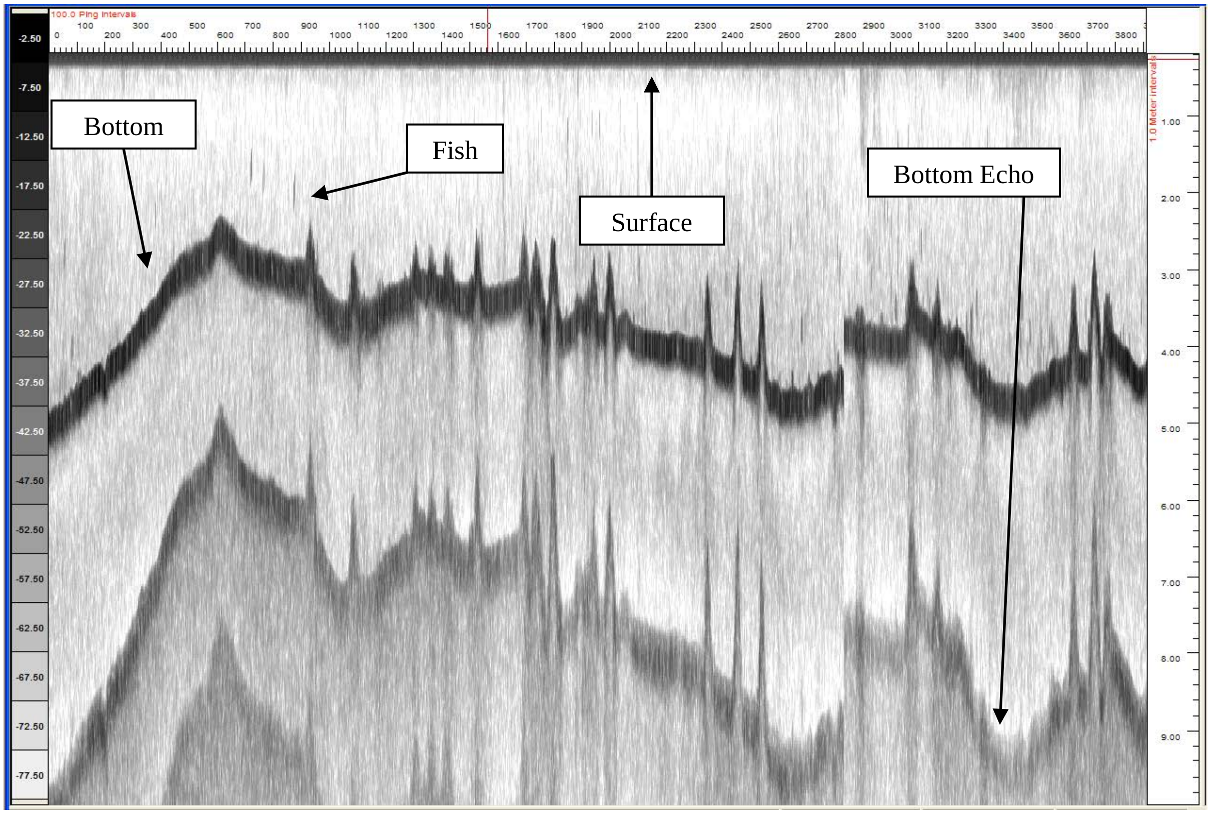


Figure 5. Example acoustic return, from Reef 2, 5/2/2011.

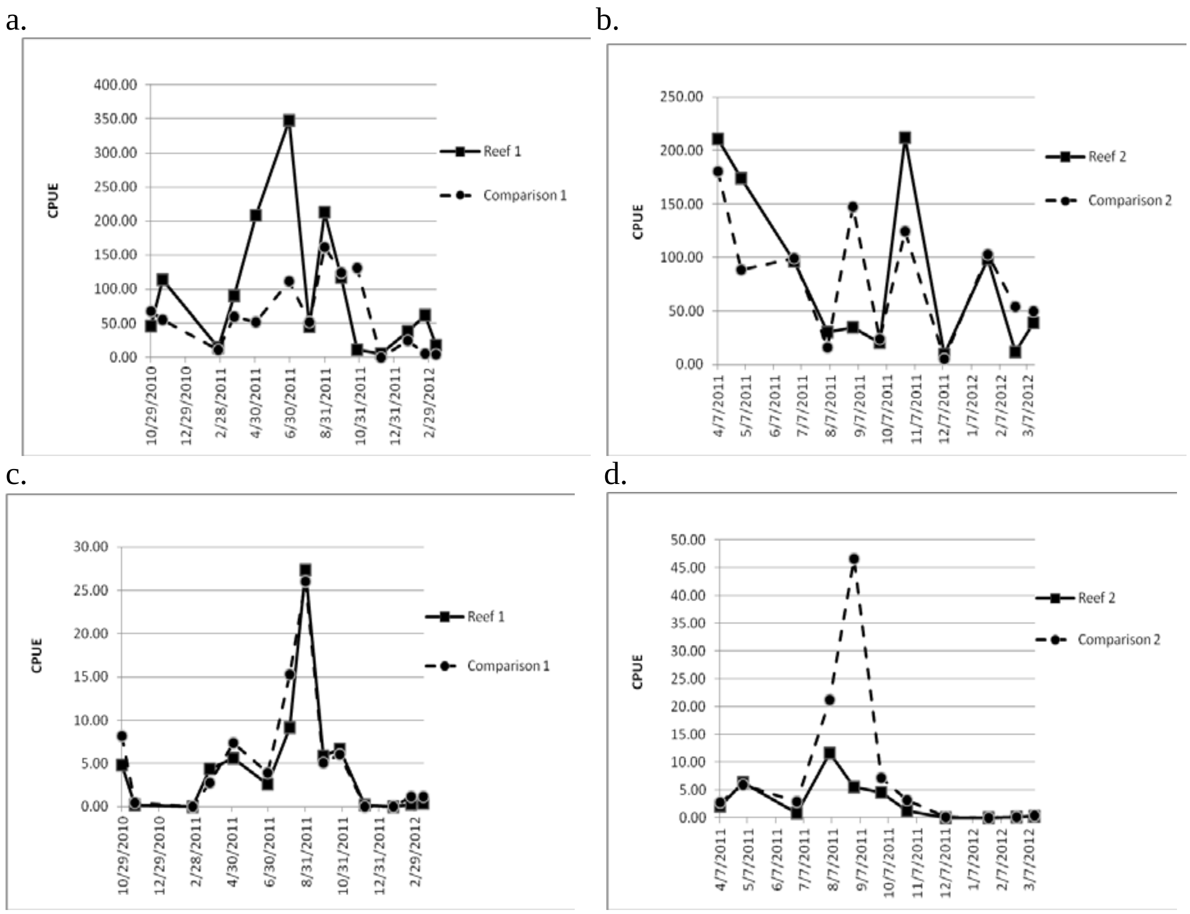


Figure 6. Hydroacoustic and Electroshocking overall fish catch per unit effort (CPUE) over time. a. Reef 1 Hydroacoustic CPUE over time. b. Reef 2 Hydroacoustic CPUE over time. c. Reef 1 Electroshocking CPUE over time. d. Reef 2 Electroshocking CPUE over time.

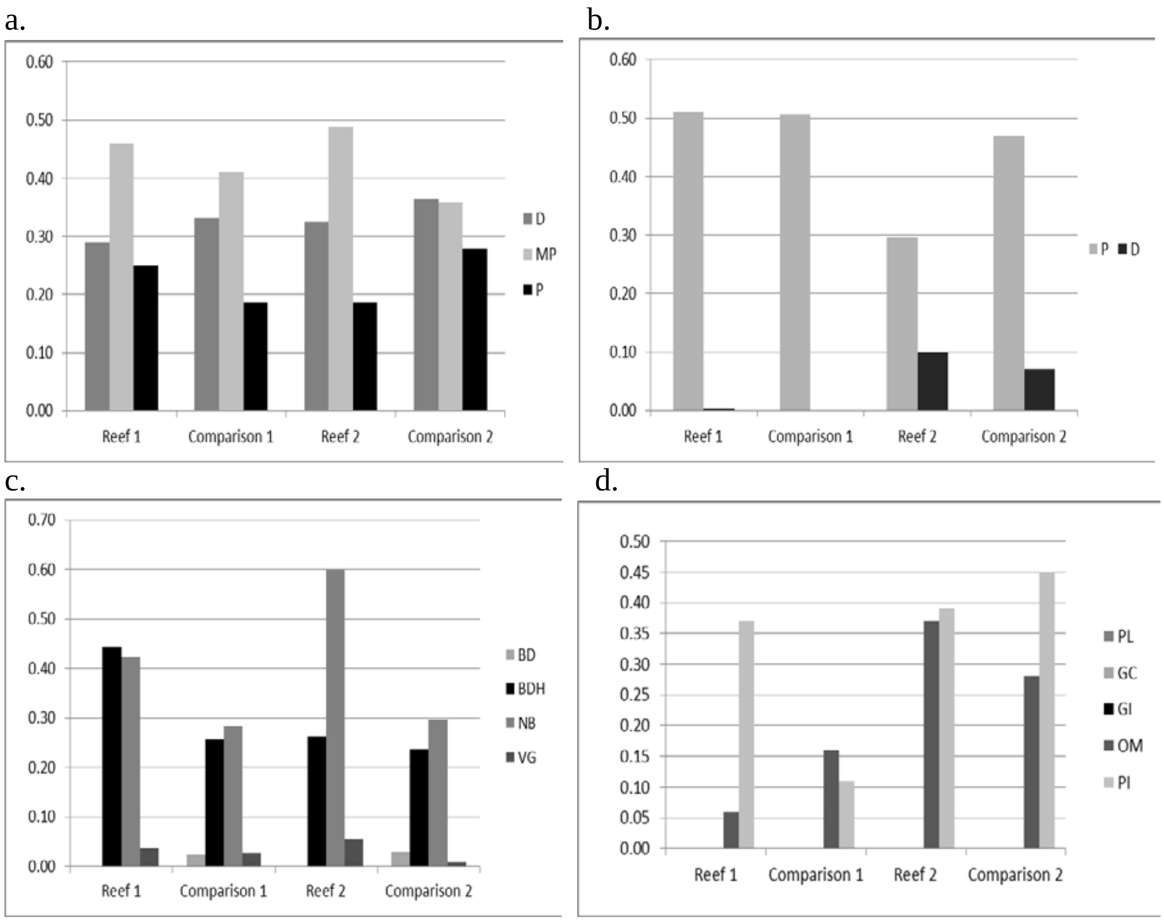


Figure 7. Water column position, reproductive, and feeding guilds. **a**. Hydroacoustic water column position, mean proportions: P= Pelagic, MP=Mid-Pelagic D = Demersal.
**b**. Electroshocking water column position, median proportions: D= Demersal, P= Pelagic. **c**. Reproductive Guilds, median proportions: BD= General Broadcasters, BDH= Broadcasters hard-bottom preference, NB= Nest builders, and VG= Vegetation Preference. **d**. Feeding Guilds, median proportions: PL= Planktivores, GI= General Invertivores, GC= General Carnivores, OM= Omnivores, PA= Parasites, and PI= Piscivores.

a. b.

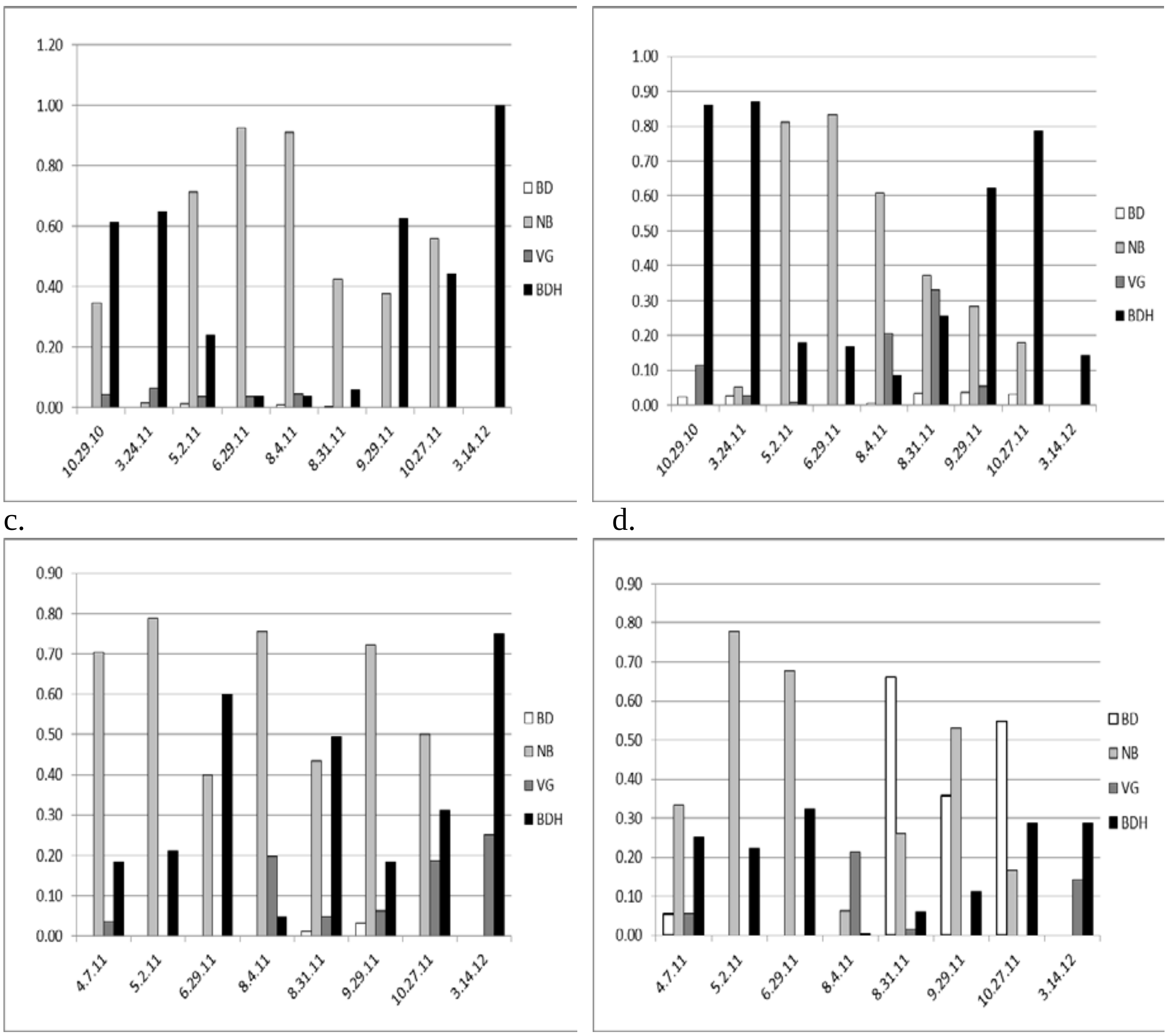


Figure 8. Reproductive guild proportions by sample date. BD= General Broadcasters, BDH= Broadcasters hard-bottom preference, NB= Nest builders, and VG= Vegetation Preference. A. Reef 1. B. Comparison 2. C. Reef 2. D. Comparison 2.

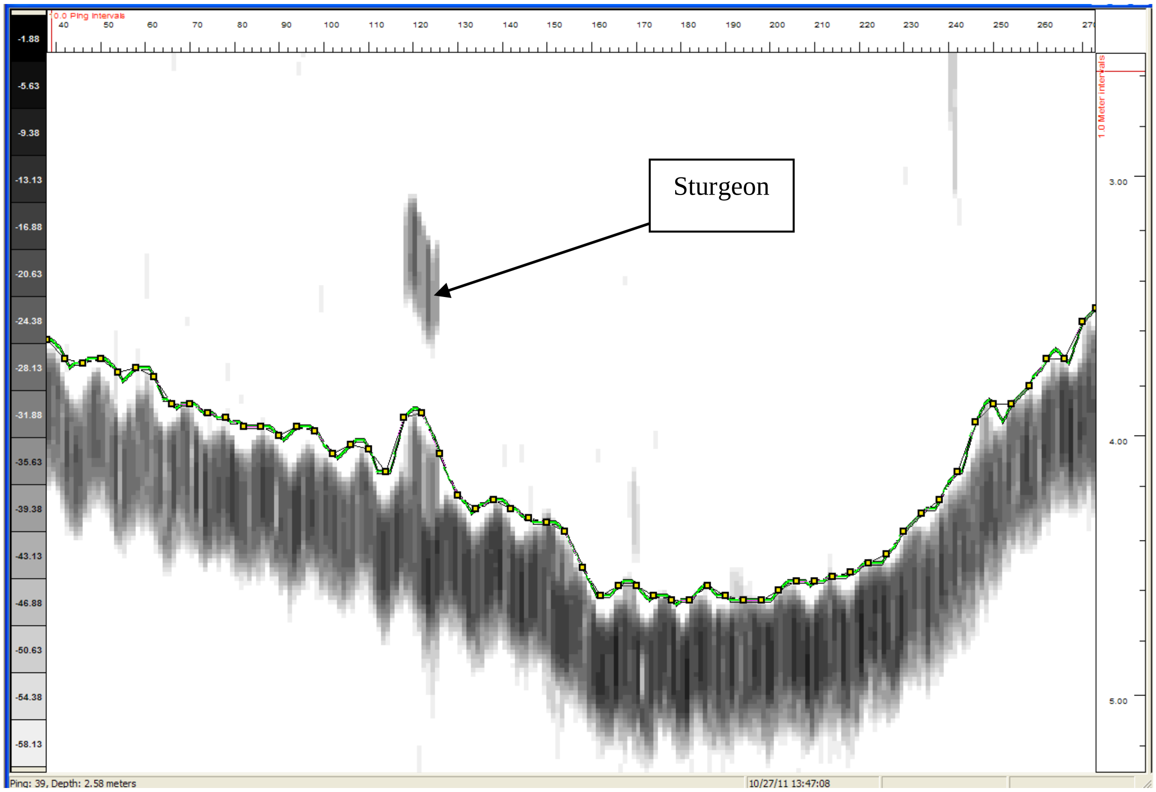


Figure 9. Possible Atlantic sturgeon pinged on 10/27/2011 Comparison 2. Target Strength= -20 dB.